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Establishment of Computational Thinking in the Interdisciplinary Education of Offshore Foundation Engineering

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ABSTRACT

To bridge the gap between learning and practice, the Ministry of Education of Taiwan has proposed educational thinking of "connecting compulsory courses with real engineering problems" to promote the New Engineering Education Method Experiment and Construction (NEEMEC) program. The offshore wind energy industry has rapidly developed in Taiwan, and this study intends to acquaint students with this industry. Because one requirement of the NEEMEC program is to develop new course handouts, the authors have taken practical engineering problems, multidisciplinary knowledge integration, and numerical software applications as the key elements for producing new handouts. The research plan was implemented by following the "conceive, design, implement, and operate" education framework and project-based learning; furthermore, the concept of computational science and engineering was leveraged to equip students with computational thinking skills. In this study, practical engineering problems were combined with the three compulsory courses in the Department of Civil Engineering: Engineering Mathematics, Soil Mechanics, and Foundation Engineering. In addition, students were guided to verify theories and present their calculation results by coding and conducting numerical simulation. In this plan, graduate students were trained to become teaching assistants to help university students comprehend the content of handouts, solve calculation exercises, and program code required for their homework projects, as well as take students to off-campus field engineering visits. Finally, this study also used the learning results and feedback of students as references for future pedagogical practices.

Keywords: Engineering education, CDIO, Project-based-learning (PBL), Numerical simulation software, Computational thinking.

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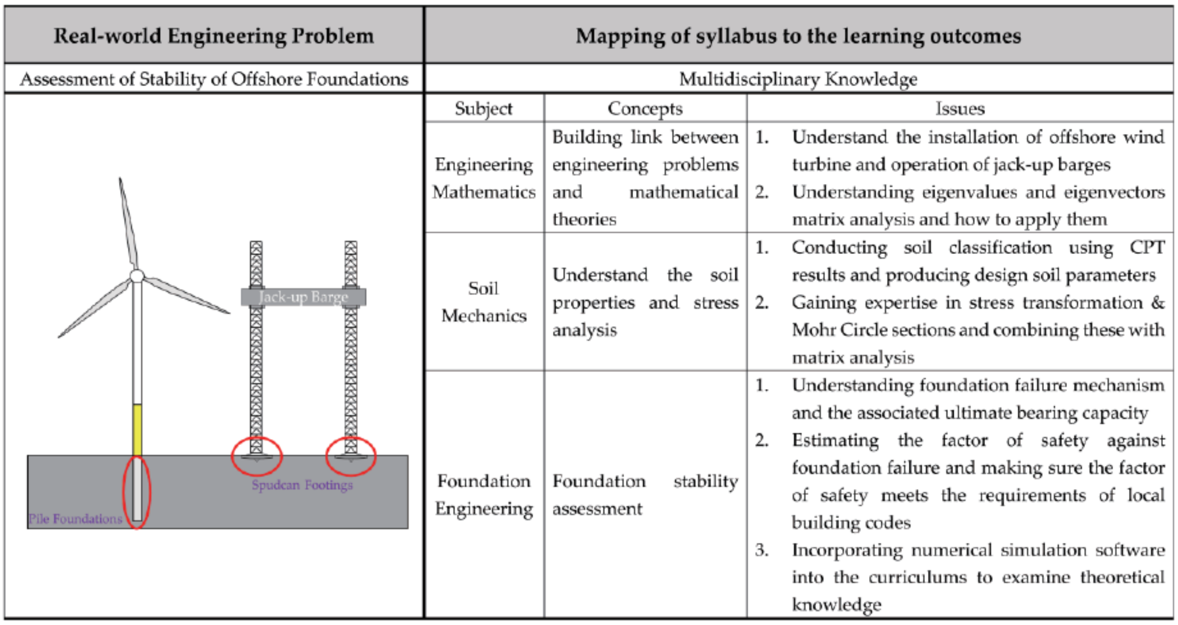
1 INTRODUCTION

The Taiwan government proclaimed relevant regulations in 2012 to promote the development of offshore wind industries, and a 5.5GW installation capacity is expected to be completed by 2025. With the development of offshore wind farms, it is obvious that more graduates from civil engineering will enter the workforce in this industry. To enable students to meet the requirements of the real-world engineering, this study guides them to understand offshore engineering by conducting required engineering projects. Structures are usually constructed in ground and foundations can transfer the load of structures into soils. There are a variety of foundation types, and the pile foundation is the common type in offshore wind farms in Taiwan. In addition, jack-up barges are widely applied in offshore engineering and used for transportation and hoisting of the components of offshore wind turbines, as shown in Figure 1. After arriving at the specific site, jack-up barges rest the spudcan footings and stand on the seabed, becoming an offshore platform.

Figure 1. Jack-up Barge and Wind Turbine Installation. (Søfart, 2020)

Professional civil engineers implement engineering projects only if they have enough expertise in civil engineering. However, according to the authors' teaching experience, many students are weak in integrating and applying their cumulative knowledge to complete a project. Hence, the authors conceived and designed homework projects for students to integrate course knowledge learned from Engineering Mathematics, Soil Mechanics, and Foundation Engineering. Figure 2 demonstrates the course knowledge connection to a real-world engineering problem; the syllabus maps to the specified issues to lead students to analyze the stability of offshore foundations. Footing stability is always one of the most critical issues for offshore foundations, including pile foundations of wind turbines and spudcan footings of jack-up barges. The stress states of soil elements below a footing after loading must be lower than the ultimate bearing capacity. In engineering mathematics, the knowledge of the matrix eigenvalue problem in linear algebra is utilized to compute the stress state of a soil element at any orientation. Students learn soil properties and stress increments due to external loading in soil mechanics. Under plane stain conditions, Mohr's circle provides an unsophisticated and graphic approach to calculate the stress state. The concept of the foundation ultimate bearing capacity to the associated failure mechanism is established in the foundation engineering courses. By connecting knowledge of the three courses, the stability of a footing can be evaluated by the procedures mentioned above. The assignments and homework projects of each course are training for students to acquire relevant knowledge.



Real-world Engineering Problem	Mapping of syllabus to the learning outcomes		
Assessment of Stability of Offshore Foundations	Multidisciplinary Knowledge		
	Subject	Concepts	Issues
	Engineering Mathematics	Building link between engineering problems and mathematical theories	1. Understand the installation of offshore wind turbine and operation of jack-up barges 2. Understanding eigenvalues and eigenvectors matrix analysis and how to apply them
	Soil Mechanics	Understand the soil properties and stress analysis	1. Conducting soil classification using CPT results and producing design soil parameters 2. Gaining expertise in stress transformation & Mohr Circle sections and combining these with matrix analysis
	Foundation Engineering	Foundation stability assessment	1. Understanding foundation failure mechanism and the associated ultimate bearing capacity 2. Estimating the factor of safety against foundation failure and making sure the factor of safety meets the requirements of local building codes 3. Incorporating numerical simulation software into the curriculums to examine theoretical knowledge

Figure 2. Connections of real-world engineering problems and knowledge from courses.

2 BACKGROUND

2.1 Project-based learning (PBL)

The American Society for Engineering Education has pointed out that engineering education should not only focus on theories or experiments, but also provide relevant projects for students to practice (Carmenado et al., 2015; Augustine and Vest, 1994). University engineering education must integrate topics that are in line with future trends into the education system, thereby providing students with a project-based learning (PBL) environment that can support them in adapting well to future needs.

Chinowsky et al. (2006) noted that universities should provide a PBL environment for students to build their own knowledge systems. Accordingly, universities will have a higher likelihood of producing college students who can apply what they have learned to real-world problems and continue to be self-learners. Teachers apply PBL teaching principles in university engineering education and establish a PBL environment with real-world engineering problems as the main guideline, and students participate in the projects in teams. In the PBL environment, teachers guide students to think about the theories and the information needed for problem-solving using problems as the focus of learning, and they will stimulate the interest of students in professional knowledge based on real engineering problems. Once students develop interest in learning professional subjects, their learning style change from passively receiving knowledge to actively exploring professional knowledge required for a project. While overcoming challenges in solving real engineering problems, students will develop the habit of autonomous learning through continuous trials and errors as well as independent thinking. Students will explore real engineering topics and challenges in a practical environment with teamwork, thereby cultivating their problem-solving ability using professional knowledge as well as their communication skills (Figure 3).

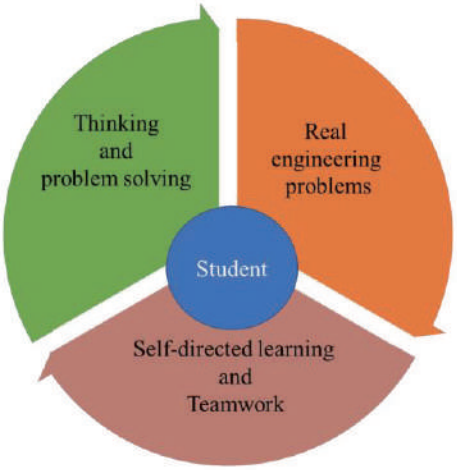


Figure 3. Project-based learning (PBL).

2.2 Conceive, Design, Implement, Operate (CDIO)

Engineering education should be oriented toward training students to become engineering professionals who can solve problems independently. However, to become a successful engineer, students must possess the following qualities: basic professional knowledge, ability to apply computer science, and sensitivity to global trends. With the rapid spread of information on the Internet in recent years, an educational model that focuses purely on professional theories may cause graduates who only have professional knowledge to be unable to accurately determine the correctness of various types of information in the workplace. When the relation between basic subjects and practice is lacking in a curriculum, a gap is created between industry and academia, which also affects the inclination of students to learn in a classroom. If engineering departments can incorporate industry-related topics into teaching professional curriculums, they will be able to cultivate the ability of students to deal with rapidly changing global trends and effectively integrate what they have learned to solve practical problems. In 2000, the Massachusetts Institute of Technology (MIT), Chalmers University of Technology, Linköping University, and KTH Royal Institute of Technology jointly promoted the conceive, design, implement, operate (CDIO) educational framework (Figure 4), which is the latest achievement in engineering education transformation worldwide. The CDIO educational framework aims to guide students to develop their ability to solve real-world engineering problems in a problem-solving process by constructing an education context related to real problems in the industry. A curriculum based on the CDIO framework has the following characteristics: (a) specific theoretical knowledge and professional skills in a subject are included in each course or learning process to equip students with the appropriate foundation for becoming future engineers and (b) the professional engineering skills acquired in the courses are highly related to each other (Crawley et al., 2007).

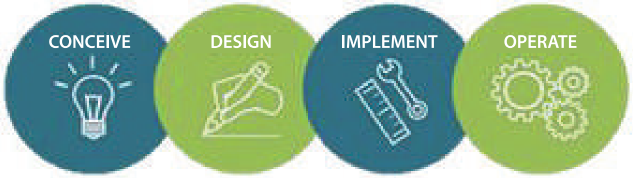


Figure 4. CDIO education framework. (Worldwide CDIO Initiative, n.d.)

2.3 Computational Science and Engineering (CSE)

Mathematics provides the theoretical basis for many disciplines, whereas engineering is the practical application of mathematical theories. However, the complex conditions in actual engineering frequently cannot be completely solved using the mathematical theories given in textbooks; as an alternative, computer numerical simulations and calculations are required. Owing to the rapid advancement in the computing speed of computers, many scientists and engineers have been employing computer science tools to deal with scientific problems that were once considered difficult to solve. Therefore, current engineering education must combine mathematics, engineering, as well as computer calculations. Yasar and Landau (2003) pointed out that computer science and engineering (CSE) is a multidisciplinary combination of computing technology, tools, and knowledge required to solve modern scientific and engineering problems. By leveraging the CSE model in higher education, students can be trained to become the next generation of engineers with computational thinking skills, which will assist them in comprehending theories based on actual engineering problems and use computer tools to meet the real-world engineering needs (Figure 5).

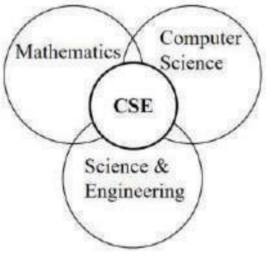


Figure 5. Computational science and engineering. (redrawn from Yasar and Landau, 2003)

2.4 New Engineering Education Method Experiment and Construction

Higher education institutions serve as important modes for the public to obtain professional knowledge. The knowledge provided by schools must meet the needs of industry, and the graduates must gain problem-solving skills. In this era, with rapidly updating engineering technology and information, classic textbooks or teaching content in classrooms cannot promptly integrate current engineering advances, and students are also unable to connect it with their professional knowledge and apply it appropriately, thereby leading to a low inclination to learn. To bridge the "gap between learning and practice," MIT and other institutions have jointly proposed an innovative educational framework, CDIO, as mentioned above. In addition, the Ministry of Education of Taiwan has proposed the educational thinking of "connecting compulsory courses with real engineering problems" to promote the "New Engineering Education Method Experiment and Construction" (NEEMEC) program (New Engineering Education Method Experiment and Construction, n.d.). The NEEMEC program includes four years of A-type projects and one and a half years of B-type projects. Under the A-type projects, a department will reorganize and renew the core undergraduate curriculum over four years of planning, experimenting, and implementing. Under the B-type projects, teams of faculty members will work on clusters of three or more undergraduate courses to develop course organization, contents, and methods coordinatively for one and a half years.

3 COURSE MAP OF B-TYPE PROJECT OF DEPARTMENT

In response to the rapid changes in real-world needs, the educational objectives for students in an engineering department should not only focus on teaching theoretical knowledge but also cultivate the ability of students to think, analyze problems, and apply what they have learned to solve problems. To comply with the wind power policy of the government and also ensure consistency between the development objectives of students and the future trends of the industry, the first author—with his years of working experience in the offshore oil and gas industry in the US as the foundation—led the department to successfully obtain the NEEMEC B-type project titled "The Theoretical Design and Practical Application of Smart Construction on Onshore and Offshore Wind Power Facilities" in 2019.

The authors and colleagues in the department have specified various keys of the CDIO framework for the implementation of the NEEMEC plan: (a) The object of educating engineers should contain real-world engineering needs, in additional to theoretical knowledge, and the teaching methods can interest students and then encourage them to engage in self-directed learning. (b) With civil engineering professional knowledge at the core, students employ available information technology to search for necessary information and data. Every student organize the collected information and data, and subsequently combine his/her own civil engineering knowledge to design solutions for the problems. (c) To implement computational thinking, the students are required to conceive some engineering projects and then transform their design into numerical models by using advanced numerical simulation software, such as Fast Lagrangian Analysis of Continua (FLAC), SAP2000, ETABS, or MATLAB. (d) Courses contain team-based homework projects that require students to integrate the theoretical knowledge and skills in numerical simulations. By conducting the homework projects, students can build up their own problem-solving abilities and apply them to solve other problems in the future.

Figure 6 shows the new course map for "The Mechanics Analysis and Applications of Wind Turbine Towers" course group in the project, which includes two major categories: geotechnical engineering and structural engineering. The authors are responsible for three courses in the course group: Engineering Mathematics, Soil Mechanics, and Foundation Engineering. The authors have combined traditional mechanics courses with practical topics in offshore geotechnical engineering, thereby guiding students to move from onshore engineering to offshore engineering. To create a PBL environment, the teachers have incorporated practical engineering cases involving the design and construction of offshore wind turbines into the teaching of fundamental mechanics courses.

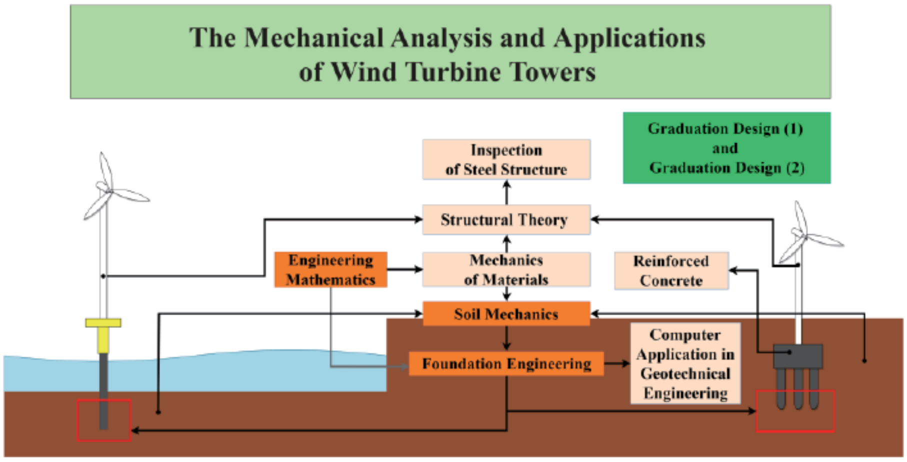


Figure 6. Course map of The Mechanics Analysis and Applications of Wind Turbine Towers.

The B-type project implementation, in addition to combining knowledge from the classroom with offshore wind power topics, is expected to enable students to experience knowledge sources outside the classroom in person. This allows establishing a tighter relation between professional knowledge from the classroom and the real-world engineering industry. The participating teachers in the project have planned multiple off-campus engineering visits to help students gain a thorough understanding of real-world engineering issues. For example, a visit was organized for the Taichung Port Project in 2020, where the first author led the students to visit the project progress status of offshore wind power ports (Figure 7).

Figure 7. Field visit to Taichung port project.

4 INTRODUCTION TO GEOTECHNICAL ENGINEERING OF OFFSHORE WIND POWER

4.1 Curriculum development concept

In the present NEEMEC project, the authors are responsible for three compulsory courses related to offshore geotechnical engineering: Engineering Mathematics, Soil Mechanics, and Foundation Engineering. Based on the concepts of CDIO and CSE, the authors integrated the course content into a newly developed comprehensive handout, An Introduction to Geotechnical Engineering of Offshore Wind Power, which demonstrates the interdisciplinary nature of offshore geotechnical engineering. The newly developed handout is divided into three parts corresponding to the three courses: Engineering Mathematics, Soil Mechanics, and Foundation Engineering. The key to design for the course handout and teaching is as follows: (a) The professional theoretical knowledge of all courses must be related. (b) The course content and homework projects contain real-world engineering problems. (c) Numerical software must be applied in conjunction with the classic textbooks for hands-on implementation in the three courses. As shown in Figure 8, the course starts from Engineering Mathematics, in which students learn about engineering problems such as buckling of jack-up barge legs and lateral capacity of wind turbine piles, and understand the corresponding differential equations, matrix analyses, and other mathematical theories. In the course Soil Mechanics, students learn about the physical properties of soil, laboratory tests, and in-situ cone penetration tests (CPTs), and also gain an understanding of the mathematical eigenvalue problem in stress analysis. Finally, the knowledge acquired from the above two courses is applied in the bearing capacity assessment of the foundation placed on homogeneous soils or layered soils, and numerical software FLAC and MATLAB are employed for the analyses.

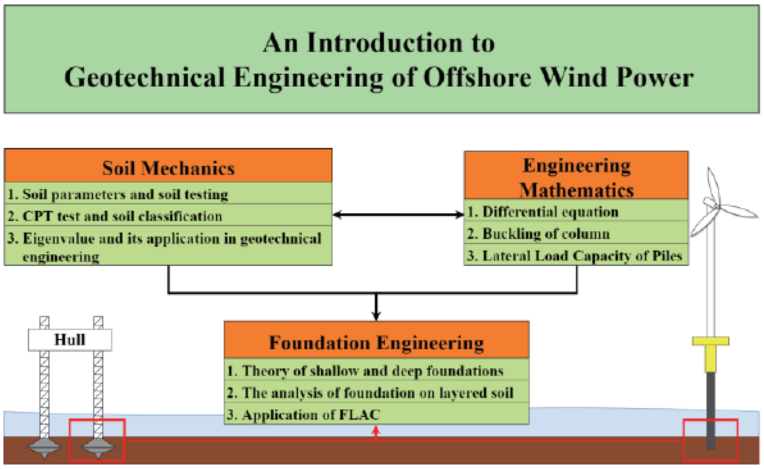


Figure 8. Course map of an Introduction to Geotechnical Engineering of Offshore Wind Power.

The course handout aims to strengthen the ability of students to connect and apply the professional knowledge acquired from the three professional courses, help them reflect on the knowledge learned in the classroom, and apply numerical software in practical engineering during after-class studies. When a course proceeds to a certain stage, students can practice the homework projects in the course handout by themselves. The purpose of the homework projects is to encourage students to integrate professional theories and apply numerical software and to present written report results at the end of the semester. Here, the Soil Mechanics course, which corresponds to Part 2 of the course handout, is discussed as an example. In Soil Mechanics, real-world engineering problems are used to connect with the matrix analysis in Part 1 "Engineering Mathematics" and the foundation stress analysis in Part 3 "Foundation Engineering." The course handout cites the in-situ geotechnical information of the offshore wind turbine locations (Figure 9) (Chi, 2019；Taiwan Power Company, 2018). The objective is to guide students to understand the content of an actual engineering report and the role of geotechnical engineering in overall offshore wind power. First, students gain an understanding of how soil properties are obtained from in-situ tests based on soil boring data. Moreover, they learn how more detailed information about the soil distributions in the strata at an engineering site is acquired through geophysical exploration based on the boring data of the site. Subsequently, students are guided to deliberate on how to analyze the mechanical parameters measured by an in-situ CPT test using MATLAB and classify the soil types at the site. The purpose of the preliminary classification is to choose appropriate laboratory soil tests for the different types of soils to obtain corresponding engineering properties. Finally, once students have comprehended the various soil tests and engineering properties of soils, the matrix eigenvalue problem in engineering mathematics and Mohr’s circle in soil mechanics are connected in the course handout and applied to stress analysis in foundation engineering. After students have mastered the mathematical and mechanical principles and the calculation processes, they use numerical software FLAC and MATLAB to analyze practical engineering problems, which is also the focus of the course handout. By connecting knowledge of different subject areas and learning computer numerical software, the authors hope to train students into the engineers the industry needs.

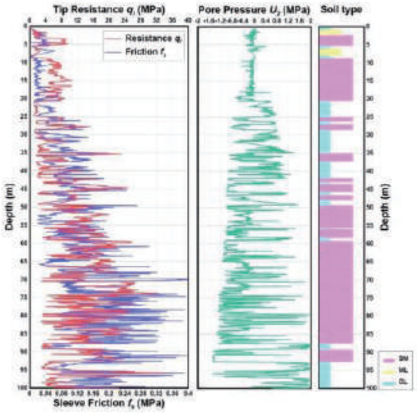


Figure 9. In-situ soil CPT profiles. (Chi, 2019; Taiwan Power Company, 2018)

4.2 Content of interdisciplinary course handouts

In the field of civil engineering, the concept of stress analysis is essential and commonly applied. To evaluate stress components on an element, Mohr's circle based on mechanical theory can be used; this approach is generally included in theoretical textbooks. However, stress analysis of an element can also be conducted by evaluation of a stress matrix. It can be seen from the above summary that students can evaluate the stress of an element using the two methods of Mohr's circle and matrix analysis. However, according to the teaching experience of the authors, owing to the poor connection between mechanical analyses and mathematical theories, students consider these two methods to be independent of one another, which makes it challenging for them to unify professional knowledge among disciplines. In view of this, the authors will lead students to investigate the eigenvalue and eigenvector problems in engineering mathematics from the perspective of soil mechanics stress analysis while developing the course handout and teaching in the classroom. It is worth noting that the PBL model is adopted here; in the course handouts, the topic of uniform vertical loading on an infinite strip footing on ground surface is introduced, and students are guided to apply mathematical and mechanical theories to perform the analysis. To complete the homework projects, students are required to use the advanced numerical simulation software FLAC. Finally, students will use the numerical analysis results for comparison with and verification of the obtained analytical solutions.

4.2.1 Stress transformation and Mohr's circle

If the stresses at a point in an element (i.e., σ_x, σ_z, $\tau_{xz} = \tau_{zx}$) are known (as shown in Figure 10), the normal stress (σ_θ) and the shear stress (τ_θ) on an inclined plane can be determine by the following equation:

$$\begin{cases} \sigma_\theta = \dfrac{\sigma_x + \sigma_z}{2} + \dfrac{\sigma_x - \sigma_z}{2} cos2\theta + \tau_{xz} sin2\theta \\ \tau_\theta = -\dfrac{\sigma_x - \sigma_z}{2} sin2\theta + \tau_{xz} cos2\theta \end{cases} \tag{1}$$

and

$$\left(\sigma_\theta - \frac{\sigma_x + \sigma_z}{2}\right)^2 + \tau_\theta{}^2 = \left(\frac{\sigma_x - \sigma_z}{2}\right)^2 + \tau_{xz}{}^2 \tag{2}$$

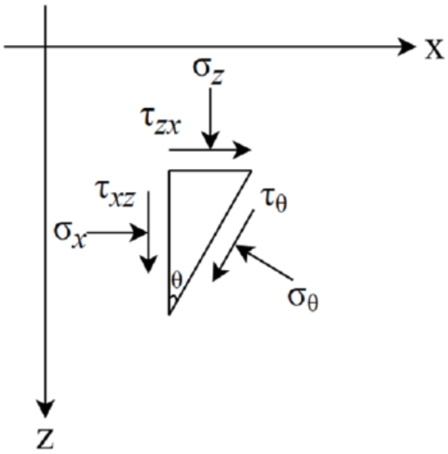


Figure 10. Stresses on an inclined plane.

Eq. (1) is the stress transformation equation, which shows that the magnitudes of normal and shear stresses change with the inclined plane. Furthermore, Eq. (2) points out that the change trajectory of σ_θ and τ_θ form a circle, which is called Mohr's circle (Figure 11). It can be seen from the figure that if the element is under the plane strain condition, the associated maximum principal stress (σ_1) and minimum principal stress (σ_3) are respectively as follows:

$$\begin{cases} \sigma_1 = \dfrac{\sigma_x + \sigma_z}{2} + \sqrt{\left(\dfrac{\sigma_x - \sigma_z}{2}\right)^2 + {\tau_{xz}}^2} \\ \sigma_3 = \dfrac{\sigma_x + \sigma_z}{2} - \sqrt{\left(\dfrac{\sigma_x - \sigma_z}{2}\right)^2 + {\tau_{xz}}^2} \end{cases} \tag{3}$$

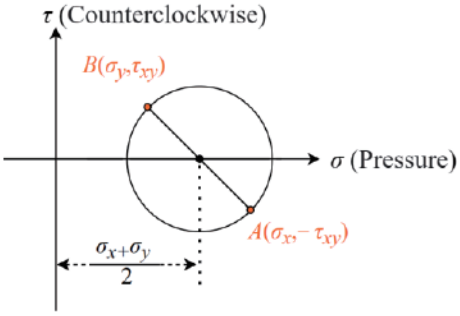


Figure 11. Mohr's circle.

4.2.2 Stress matrix and eigenvalue problem

In the field of geotechnical engineering, the plane strain condition is widely adopted in stress analysis, which can be used to simplify a three-dimensional problem into two-dimensional conditions for analysis. Suppose the stress condition of an element is as shown in Figure 12. For equilibrium, the corresponding stress matrix ($\boldsymbol{\sigma}$) can be expressed as follows:

$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_x & \tau_{xz} \\ \tau_{xz} & \sigma_z \end{bmatrix} \tag{4}$$

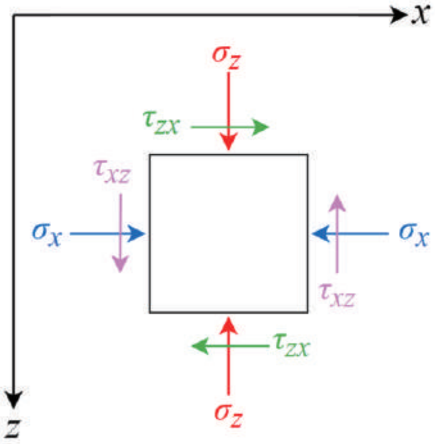


Figure 12. Notations for normal and shear stresses for plane strain case.

The eigenvalue (λ) of Eq. (4) could be expressed as follows:

$$\lambda = \frac{(\sigma_x + \sigma_z) \pm \sqrt{(\sigma_x + \sigma_z)^2 - 4(\sigma_x\sigma_z - {\tau_{xz}}^2)}}{2} \tag{5}$$

Because the stress matrix ($\boldsymbol{\sigma}$) is a real symmetric matrix, the associated eigenvalue will be a real number. Furthermore, given the following conditions:

$$\begin{cases} \sigma_c = \dfrac{\sigma_x + \sigma_z}{2} \\ r = \sqrt{\left(\dfrac{\sigma_x - \sigma_z}{2}\right)^2 + {\tau_{xz}}^2} \end{cases} \tag{6}$$

Eq. (5) can be expressed as

$$\begin{cases} \lambda_1 = \sigma_c + r \\ \lambda_3 = \sigma_c - r \end{cases} \tag{7}$$

It is worth noting that Eq. (7) shows the eigenvalues of the stress matrix, which are consistent with the results obtained from the Mohr's circle (Eq. (3)).

To obtain the corresponding eigenvectors of stress matrix ($\boldsymbol{\sigma}$), Eqs. (8) and (9) can be used (Chi and Lin, 2019).

$$\begin{bmatrix} \sigma_c + rcos(t) - (\sigma_c + r) & rsin(t) \\ rsin(t) & \sigma_c - rcos(t) - (\sigma_c + r) \end{bmatrix} \begin{bmatrix} x_{11} \\ x_{21} \end{bmatrix} = \mathbf{0} \tag{8}$$

$$\begin{bmatrix} \sigma_c + rcos(t) - (\sigma_c - r) & rsin(t) \\ rsin(t) & \sigma_c - rcos(t) - (\sigma_c - r) \end{bmatrix} \begin{bmatrix} x_{13} \\ x_{23} \end{bmatrix} = \mathbf{0} \tag{9}$$

where t represents an angle. Obviously, the unit eigenvectors corresponding to λ_1 and λ_3 are Eqs. (10) and (11).

$$\boldsymbol{u_1} = \begin{bmatrix} u_{11} \\ u_{21} \end{bmatrix} = \begin{bmatrix} cos\left(\dfrac{t}{2}\right) \\ sin\left(\dfrac{t}{2}\right) \end{bmatrix} \tag{10}$$

$$\boldsymbol{u_3} = \begin{bmatrix} u_{13} \\ u_{23} \end{bmatrix} = \begin{bmatrix} -sin\left(\dfrac{t}{2}\right) \\ cos\left(\dfrac{t}{2}\right) \end{bmatrix} \tag{11}$$

The analysis results of Eqs. (10) and (11) show that the eigenvectors corresponding to the maximum and minimum principal stresses can form a rotation matrix. In addition, the rotation angle of the eigen direction ($t/2$) is exactly half of the rotation angle (t) of the Mohr's circle, as shown in Figure 13.

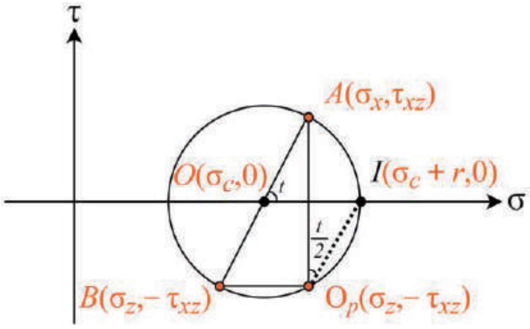


Figure 13. Mohr's circle rotation diagram. (redraw from Chi and Lin, 2019)

4.3 Homework Project: Uniform Vertical Loading on Infinite Strip on Surface

A structure is typically built on soil; thus, from the soil perspective, it can be considered as a problem of loading. For the elastic loading of a dam, a strip footing, and other structures (Figure 14), because their lengths (L) are much greater than the foundation width (B), the plane strain condition can be used to simplify the analysis. Based on the theory of elasticity, Poulos and Davis (1973) purposed that when a soil element (point P in Figure 15) is subjected to a uniform vertical load on an infinite strip foundation on a surface, the increment in the stress can be expressed as follows:

$$\Delta\sigma_z = \frac{q}{\pi}[\alpha + \sin\alpha\cos(\alpha + 2\delta)] \tag{12}$$

$$\Delta\sigma_x = \frac{q}{\pi}[\alpha - \sin\alpha\cos(\alpha + 2\delta)] \tag{13}$$

$$\Delta\tau_{xz} = \frac{q}{\pi}\sin\alpha\sin(\alpha + 2\delta) \tag{14}$$

The symbols in the above equations refer to Figure 15.

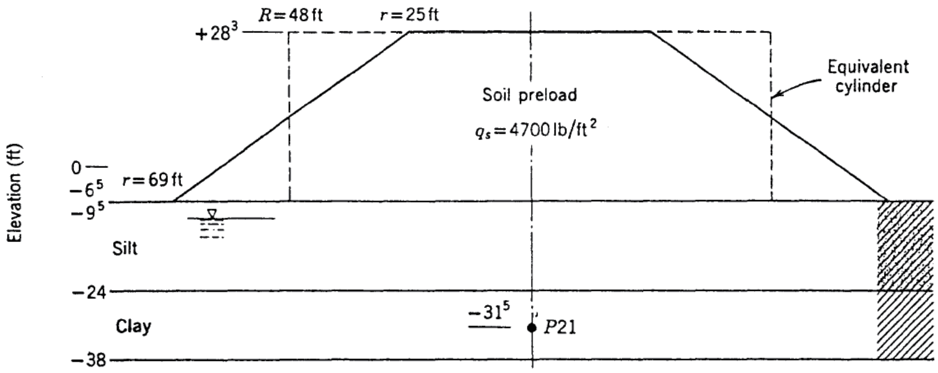


Figure 14. Schematic of increment in stress caused by embankment. (Lambe and Whitman,1969)

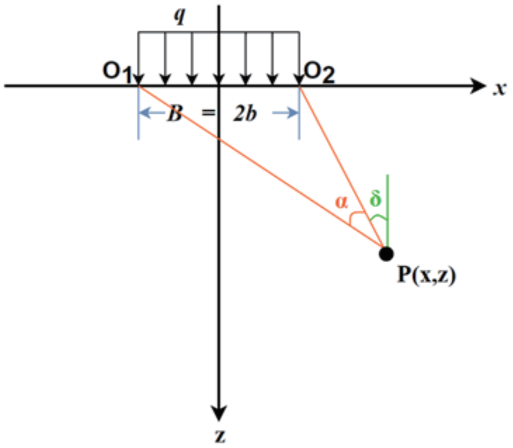


Figure 15. Uniform vertical loading on an infinite strip. (redraw from Das, 2008)

Figure 16 shows the dimensionless results obtained from Eq. (14). As can be seen in the figure, when an external load is applied, an increment in shear stress ($\Delta\tau_{xz}$) will be generated in part of the soil layer, i.e., the principal stress axis will rotate along the y-axis (outward perpendicular to the paper plane). The evaluation of the principal stress magnitude, the directions of the principal stress, and maximum shear stress are of major significance, and they are important parameters for determining the failure envelope of soils. Moreover, the problem of strip footing loading can also be analyzed using numerical simulation software. The obtained distribution pattern (Figure 17) of the increment in the shear stress is consistent with the theoretical results.

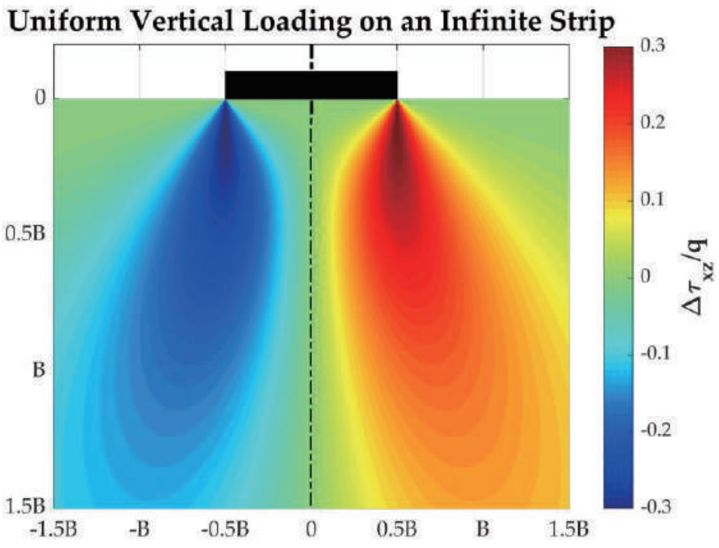


Figure 16. Normalized result of $\Delta\tau_{xz}$. (Chi, 2019)

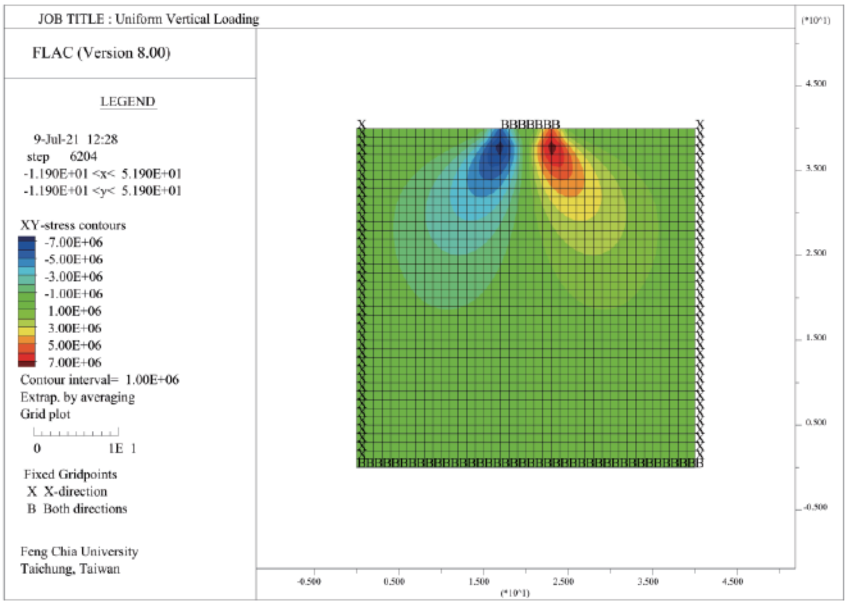


Figure 17. Analysis result using FLAC simulation. (Chi, 2019)

5 RESULTS AND DISCUSSIONS

In this study, multidisciplinary knowledge was interconnected to guide students to understand the onshore and offshore wind power industry. In addition, lecturers incorporated real-world engineering problems into the curriculums to cultivate the problem-solving abilities of students. Figure 18 shows the teaching sequence of each subject area in the course series "An Introduction to Geotechnical Engineering of Offshore Wind Power" and the corresponding real-world engineering projects. It can be seen from the figure that the homework projects that students are required to complete are as follows: (I) Engineering Mathematics—the theory of differential equations will be applied to the analyses of column buckling and lateral load capacity of piles; (II) Soil Mechanics—the teacher will explain the various soil tests in the classroom and introduce soil information of the western Taiwan sea area, and students are required to classify the soils. Furthermore, the authors link stress transformation equations and the Mohr's circle in the stress analysis section of soil mechanics to the eigenvalue problem of engineering mathematics (Section 4.3); (III) Foundation Engineering—the authors introduce advanced theories of the bearing capacity of foundations, lead students to analyze the bearing capacity of a footing on layered or nonhomogeneous soil, and utilize numerical simulation software FLAC for verification.

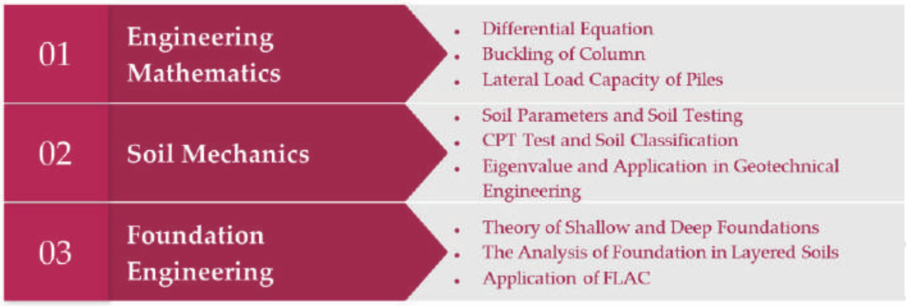


Figure 18. Arrangement of curriculums for Introduction to Geotechnical Engineering of Offshore Wind Power.

In the CDIO educational framework, an educational context connected with real problems in the industry is constructed, thereby guiding students to develop their ability to solve real problems in a problem-solving process. In addition, professional engineers must possess good teamwork, communication, and problem-solving skills. In this course series, students are required to complete multiple homework projects; during these projects, students must solve the problems in teams. Using the CPT test and soil classification project in soil mechanics as an example (Figure 19), the results obtained by students based on the theories of different scholars may vary; therefore, extensive discussions within and between groups are inevitable. Students must have a comprehensive understanding of the various characteristics of the soil and use their engineering judgements to obtain relatively reasonable analysis results. Moreover, the analysis of foundation engineering requires the relevant theories learned in soil mechanics; therefore, the foundation bearing capacity analysis project in the foundation engineering course must be based on previous analysis results. In this process, the various assumptions of the teams about the in-situ soil—such as soil unit weight, soil type, and soil strata line—will affect the assessment results of the foundation bearing capacity. Similarly, to obtain a reasonable analysis result, significant communication is a must.

Due to the complexity of practical engineering problems, the use of computer software is necessary, and hence numerical simulation software is incorporated into the curriculums to examine theoretical knowledge. Most of students suppose that all software are like calculators, in that one keys in input data and then gets a solution after the "Enter" button is pressed. Nevertheless, some advanced software, such as FLAC shown in this study, are not as straightforward as students' expectations. The following list exemplifies some of the main issues:

1. Some input parameters have to be computed rather than found from soil reports.
2. Many examples in users' manuals show how to use programing code to command FLAC to compute, rather than use GUI (Graphical User Interface). Programing ability is required for users to understand examples.
3. Users have to define output parameters (solutions), and post-processing is usually required before demonstrating them.

According to the authors' observations, using engineering numerical simulation software is another challenge for students in addition to integrating and applying course knowledge to practical engineering problems. One of important targets for the authors in executing the NEEMEC program is to help students to establish the basic concepts of the how numerical simulation software operate (establish computational thinking). The example illustration from the professor in the class, the tutoring from the teaching assistants after class, and the practices from homework projects help the establishment of computational thinking for students. The theoretical approach is quite different from the numerical method, and the latter is used to assess sophisticated real-world problems.

In summary, in the course series "An Introduction to Geotechnical Engineering of Offshore Wind Power," the analysis of an offshore wind turbine pile is compulsory. To achieve this objective, students need to go through at least the following stages: (I) Conceive Stage, where students conduct feasibility assessment of the designated location of the wind farm; (II) Design Stage, where students can further select specific foundation types for detailed designs according to the in-situ soil properties, weight of the wind turbine, and other factors; (III) Implement Stage, where the objective is to present the results with numerical simulations based on the abovementioned conditions; (IV) Operate Stage, where students must consider the various problems that might be encountered by offshore foundations, such as member fatigue, soil dynamic behavior, and soil liquefaction, and establish corresponding countermeasures in the numerical model. By the implementation of a series of engineering homework projects, teachers can gradually cultivate the ability of students to solve engineering problems.

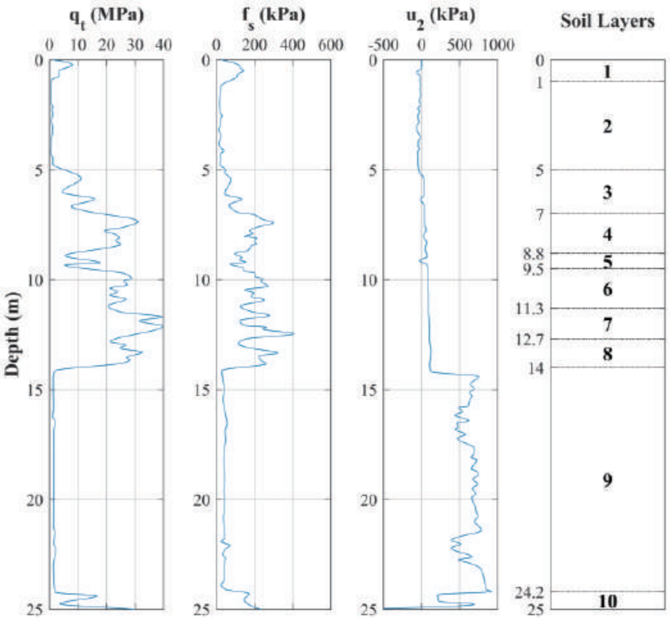


Figure 19. Soil data profile in homework project.

To evaluate the effectiveness of the teaching content on the learning of students, in this study, a survey questionnaire was issued at the end of the last unit in the course series, "Foundation Engineering". The surveyed students awarded 5 points (strongly agree) to 1 point (strongly disagree) to the questions in the questionnaire, and the final statistical results are listed in Table 1 and Table 2. As shown in Table 1, the average score for the "teaching and course handout of the course series" is the highest (4.5), i.e., the surveyed students have a clear understanding and agree with the objectives of this course series. In contrast, the average scores of both "personal ability development" and "impact on learning planning" are 4.2, which is on the relatively lower end in this survey. Because the topics of the homework projects designed in the courses are designated by the authors, students must use what they have learned in the given topics. In the CDIO educational framework, students can select appropriate topics to proceed with the follow-up stages based on their own observations and interests in the Conceive stage. Therefore, the authors will link the courses more comprehensively in the future, thereby providing more participation opportunities for students. However, the questionnaire survey content (Table 2) shows the following: (I) Question "The content of the course handout serves as an actual link between the classic textbook and real-world engineering problems" has the highest score (4.8), i.e., the respondents highly agree with the development concept of the course handout; (II) Questions "Comprehension of the knowledge of related courses is a must for solving the homework projects" and "The practice of homework projects in the course series can help familiarize with the use of numerical software" have the second highest scores (both 4.6), and these questions are related to the implementation approach of the educational objectives of this course series; (III) The score of the question "The process of solving homework projects can stimulate my motivation for self-study" indicates that there is room for improvement in this study. In addition, based on the engineering policy of Taiwan, the authors have explained the offshore wind power industry in the classroom and introduced several engineering homework projects to guide students to understand the industry. However, these topics may not meet the interests of all students taking the courses; therefore, this outcome can be adjusted in the future.

Table 1. Question categories in questionnaire.

No.	Question Category	Average Score
1	Teaching and course handout content of the course series	4.5
2	Homework projects and computational thinking practices	4.4
3	Application of numerical software	4.3
4	Personal ability development	4.2
5	Impact on learning planning	4.2

Table 2. Evaluations by students based on educational quality survey questionnaire questions and results.

Type	Question	Score
Teaching and course handout content of the course series	The training of the course handout is in line with the essential knowledge covered by each course	4.4
	The training of the course handout is in line with the development of the personal ability	4.2
	The training of the course handout is in line with the importance of teamwork	4.5
	The content of the course handout serves as an actual link between the classic textbook and real-world engineering problems	4.8
Homework projects and computational thinking practices	Comprehension of the knowledge of related courses is a must for solving the homework projects	4.6
	The design orientation of the homework projects allows me to learn numerical software from easy to difficult in order	4.3
	The practice of the homework projects in the course series can help familiarize with the use of numerical software	4.6
	After taking the course, I would like to continue to learn numerical software	4.2
Application of numerical software	In the process of applying numerical software, the integration of knowledge of various courses has been deepened	4.1
	Through the application of numerical software, the links between the theories in the curriculum and real-world engineering problems have been strengthened.	4.5
Personal ability development	The process of solving the homework projects can stimulate my motivation for self-study	4.0
	Through teamwork, I can improve my communication skills and report writing ability	4.3
Impact on learning planning	The integration of knowledge in the course series can guide me to think about the process and approach of solving real-world engineering problems	4.2
	The planning of the course series has increased my confidence to solve more complex engineering problems that are closer to reality	4.4

6 CONCLUSIONS

To train students as engineers who can solve problems independently, the authors have introduced CDIO, CSE, and PBL into pedagogic practices and established notable links between actual engineering problems, numerical software, and content of three courses. Barroso and Morgan (2009) pointed out that a project is not a tool for mastering subject knowledge but instead a link to connect different concepts, enabling students to think about how to use these concepts to solve real problems. In this study, actual engineering problems in the textbook are not only used to help students understand the content of the course but are also used to link knowledge from different courses and the application of numerical software. After being trained in the course series, students will think about how to employ numerical software to solve more practical engineering problems with greater complexity (Figure 20).

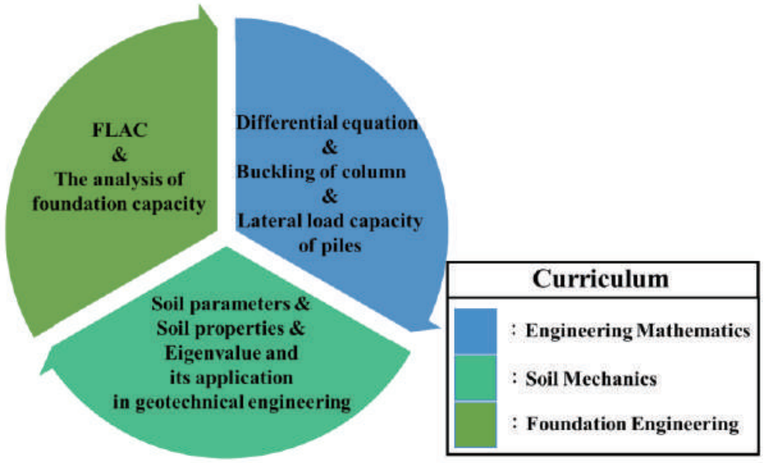


Figure 20. Integrated curriculums linked by real engineering projects.

The conclusions obtained from the current study can be listed as follows in order:

1. In this study, the teaching approaches and the course handout development are implemented by relating the knowledge of three compulsory courses (Engineering Mathematics, Soil Mechanics, And Foundation Engineering) in the civil engineering department with practical engineering problems. The results of the student questionnaire survey show that the respondents had a clear understanding of the teaching objectives of the course series, "An Introduction to Geotechnical Engineering of Offshore Wind Power."

2. The design of the homework projects can link theoretical knowledge covered in the courses with practical engineering problems; therefore, the participating students can fully apply what they have learned when dealing with a series of engineering topics. The questionnaire results also show that the introduction of relevant numerical simulation software into professional courses can help students learn about numerical software in advance.

3. To realize the above two points, the teachers must compile or develop the corresponding textbook content or teaching materials. The course handout series used in this study is a combination of the three compulsory courses of Engineering Mathematics, Soil Mechanics, and Foundation Engineering, as well as corresponding practical engineering problems. By providing organized educational content, the authors have guided students to understand the field of offshore marine engineering and cultivated professionals needed by the engineering industry in the future.

The results indicate that interdisciplinary engineering education is beneficial to the students. However, there are still some limitations and suggests, which are as follow:

1. The content of the homework projects is limited to the field of offshore engineering; however, this field may not meet the interests of all students. Therefore, in the development of future curriculums and content, more subject knowledge can be connected to provide students with a wider range of practice topics.
2. After finishing this course series, students produce a comprehensive engineering report, and some of those have a strong interest in offshore engineering and want to further explore this field. Hence, the authors hold graduation exhibitions for the undergraduate students to demonstrate their learning outcomes. By using the NEEMEC program, students acquire the ability to apply interdisciplinary course knowledge and numerical software to real-world engineering problems, and professors utilize questionnaires to understand students' learning statuses and adjust the teaching strategies of courses.

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